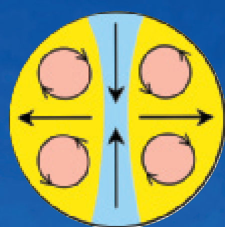
The Physics of The Sound Barrier, Brownian Motion and Tyndall's "Sonorous Vibrations"

A Supplement To



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The Physics of

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Transition to Turbulence

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KEY WORDS

Acceleration, aerodynamics, plastic air, aircraft, amplify, atoms, Mexican jumping bean, Robert Brown, chaos, mist cloud, colloid, sound cone, diffusion, intermolecular repulsive force, heat, F/18A Hornet, Kelvin, Mach I, molecular kinesis, lightning bolt, gaseous state of matter, Brownian Motion, NASA, musical notes, atomic oscillation, molecular oscillation, particles, physics, Prandtl, randomness, reflectivity, resistance, rotation, SPIV, sound sensitive, spectroscopy, spinning, coherent sound-induced split, Kinetic Theory, thunderclap, Tyndall, stereoscopic particle image velocimetry, sonorous vibrations, viscosity, conical wake, random walk, shear waves, shock wave, sound wave, wavelength, absolute zero .

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The Acceleration and Deceleration Sides of the Mach I Sound Barrier[1]

Mechanical stresses are extreme as an aircraft crosses the Mach I speed of sound threshold during acceleration and again during deceleration, revealing that there are two sides to the "sound barrier" – the posterior (acceleration) side and the anterior (deceleration) side.

Air resistance in turbulent flow varies as the square of the velocity, whereas the resistance of laminar airflow varies directly as the velocity. During acceleration, the leading edges of wings maintain laminar airflow. However, as Mach I (350 m/s) is approached, the aircraft enters air that has become so agitated by increasingly intense sound energy that it is rendered incapable of laminar flow. The leading edges now face turbulent flow resistance – 350 times that of laminar flow. The posterior edge of this high resistance area is the posterior side of the sound barrier.

The sound-energy-induced plastic air is like a gel with the density of air – an "air jelly." The air jelly in front of the aircraft is compressible and is being pushed against – and compressed by – the leading edges. This accounts for the air compression that is known to exist anterior to the leading edges and which may have been misunderstood.

Sound energy, created by aerodynamics and the engines along the line of flight, accumulates in a cone within which the aircraft becomes ever closer to the apex as it approaches Mach I. At Mach I, the aircraft's leading edges form the apex, with the sides of the cone at 45 degrees to the line of flight. At the speed of sound, the sounds generated by the aircraft will travel laterally the same distance as the plane – and the sounds it generates – will travel on the line of flight, accounting for the 45 degree angle defining the sound cone (related to the line of flight), that is filled with unlaminable plastic air. All the sound created is within the cone and is concentrated at its apex.

Doppler-induced ultrahigh ultrasound frequencies approach infinity along all of the leading edges as one nears Mach I – and the wavelengths are proportionately decreased – approaching zero. The theoretical lower limit of wavelength of such ultrasound would be twice the average distance between the centres of adjacent sound-agitated air molecules at a given temperature and pressure. Therefore, the extreme theoretical upper limit of frequency would correspond to this finite, yet ultramicroscopic, dimension.

[1] Hamilton G: Coherent Sound Energy in Transition to Turbulence. UWO Graphic Services, 2008, p 48

If one were to shrink the aircraft to point size, the apex of the cone at Mach I would be a sharp point, resulting in a perfect cone.

As Mach I is exceeded, the leading edges of the aircraft instantly enter silent laminable air, leaving behind the anterior wall of the sound barrier. The cone of air being left behind (which has been referred to as the "shock wave") is filled with intense sound energy, with extremely agitated air molecules. The air in the sound cone has the resistance of turbulent flow, 350 times greater than the silent laminar air now flowing along the leading edges. As the aircraft exceeds Mach I, the compression of the air jelly in the sound cone anterior to the leading edges is released, allowing it to expand immediately, accompanied by a decompression booming sound. This is one of the two sonic booms that characterize the breaking of the sound barrier by a supersonic jet aircraft.

In deceleration from supersonic speeds, the leading edges will strike – and pass into – the sound cone. The leading edges will immediately face the airflow resistance of turbulent air (i.e. – "plastic air") – air that is incapable of laminar flow. The airflow resistance on the leading edges will be 350 times greater than an instant earlier. The anterior (deceleration) side of the sound barrier has been breached. During further deceleration from Mach I, the turbulent resistant factors along the leading edges persist until the drop in sound intensity allows laminar flow to resume along the leading edges. It is only at this point that the physical effects of the sound barrier vanish as the aircraft recedes from the posterior side of the sound barrier.

These arguments suggest that there is a wall of sound-mediated turbulent jellied air (Prandtl's plastic flow air[2]) that has two sides: 1) the posterior side of increasingly intense sound energy and plastic air – which must be passed through during the acceleration phase – and 2) the anterior side separating the quiet zone of laminable air in front from the wall of plastic air, behind. The sound and heat insulation built into supersonic aircraft protect the aircraft's crew from cellular and body structural damage from exterior intense audible sound and ultrasound energy as the sound barrier is crossed. Animal cells rupture and calcific structures are shattered, by intense audible sound[3 4] or ultrasound.[5] However the higher the ultrasound frequency, the greater is its reflectivity, a characteristic that protects aircrew from the very high energy Doppler-induced ultrasound that is generated – and concentrated – outside the cockpit.

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2 Prandtl L and Tietjens OG: Applied hydro and Aeromechanics. Dover Publications, New York (1957), (reprint of lectures by L. Prandtl , 1934 edition): p. 30-36.

3 Gaines N: A magnetostriction oscillator producing intense audible sound and some effects obtained. Physics (1932); 3: pp. 209-229

4 Delius M: Medical applications and bioeffects of extracorporeal shock waves. Shock Waves (1994); 4 (2): 55-72

5 Wood W and Loomis AL: The physical and biological effects of high frequency sound waves of great intensity. Philosophical Magazine and Journal of Science (1927); 4: pp. 417-436

A stationary observer on the line of flight cannot hear the approaching sounds of increasingly high frequency once the ultrasound range is entered. However, as the aircraft passes the stationary observer on the line of flight as Mach I is exceeded, the Doppler-generated extremely low frequency sounds, heralded by the absolute lower limit of sound – a single massive vibration – the thunderclap (a very apt sound barrier metaphor – the "clap" of a super-supersonic lightning bolt) – signals to the stationary observer that the sound barrier has been crossed by the now receding aircraft. The thunderclap is the more dominant of the two loud booms.

Compression of Plastic "Air Jelly" by the Leading Edges as Mach I is Approached

The plastic air cone, caused by aircraft-generated sound is like a compressible jelly with the density of air. The leading edges are pushing against the jellied air in front, compressing it. As the aircraft (which lies totally within the plastic sound cone) approaches Mach I, the leading edges come closer to the anterior margins of the sound cone.

Thus, Prandtl's plastic air actually precedes the leading edges as Mach I is approached. (Prandtl would have been astonished by this concept.)

As the sound barrier is crossed the plane immediately enters a zone of silence and laminable air, releasing the compressed jellied air, which rebounds to its uncompressed state, causing the second component to the sonic boom.

A Convex Disc of Water Mist is Penetrated as Mach I is Exceeded

Suspended particles are propelled away from powerful ultrasound sources.[6] Thus, the cone of Doppler-generated intense ultrahigh ultrasound developing in front of the aircraft as Mach I is neared will sweep suspended water droplets or ice particles forwards to a position in front of the plane's nose, forming a water cloud disc. The diameter of the disc is defined by the circular cross-sectional margins of the sound cone within which it is created and remains.

[6] Lieberman LN: The second viscosity of liquids. Physical Review (1949); 75: pp. 1415-1422

As Mach I is being exceeded, the aircraft passes through this disc (NASA photo of Navy F/A-18 Hornet jet penetrating the sound barrier). The well known heating (and cooking) effects of high energy, high frequency ultrasound will raise the temperature of this disc of water droplets, compared to the air temperature outside the cone which contains plastic air.

Navy F/A-18 penetrating a water mist cloud through Mach I (NASA file photo)

Brownian Motion of Colloids in The Kinetic Theory of Fluids

It was the zigzag random Brownian Motion[7] of colloidal particles suspended in a liquid that caused Einstein to propose that there is chaotic molecular motion in the fluid states of matter and that molecular collisions with colloidal particles cause their irregular random movements[8] (Kinetic Theory). However, how can vast numbers of ultra-ultra-microscopic single molecules,

[7] Brown, Robert, "A brief account of microscopical observations made in the months of June, July and August, 1827, on the particles contained in the pollen of plants; and on the general existence of active molecules in organic and inorganic bodies." Phil. Mag. 4, 161–173, 1828

[8] Einstein A:"Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen.", Annalen der Physik; 17: 549–560

striking comparatively immense particles, randomly on all sides, from all directions, cause any microscopically visible random particle movement? The averaging effect of randomness excludes any particle movement by this mechanism. There must be another explanation.[9]

Fundamental Physics of sound transmission dictates that the relatively huge surface area of colloidal particles is being bombarded constantly – not by single molecules – which cannot budge them – but by coordinated waves of vast numbers of the fluids' molecules, as omnipresent, multifocal, omnidirectional, multi-frequency sound strikes them on all sides at the speed of sound. The human eardrum (which can be broken down into a large number of colloidal size particles) manifests this effect as molecules in waves of sound energy, focused by the ear canal, strike it at the speed of sound. Thus, environmental sound can explain Brownian Motion.

It is proposed that a modification of the Kinetic Theory of fluids can explain how laminar flow can extend down to small multiples of molecular dimensions, where the shear waves of transition may originate.[10] It is proposed that the fundamental molecular kinesis in static silent undisturbed fluid may result from the oscillation of molecules about their centres of mass with the amplitude of oscillation being directly related to the Kelvin temperature scale, with oscillation ceasing at absolute zero.

Further molecular kinesis could be related to a "random walk" type of Mexican-jumping-bean molecular movement caused by the oscillation of molecules with eccentric, very heavy atomic nuclei within force fields defined by low mass atomic electron "rings" which are incorporated into molecular structure. Diffusion is explainable in this context by the random walk motion created by the Mexican jumping bean mechanism.[11] Propulsion by waves of environmental sound energy would add to molecular kinesis and to the diffusion of molecules.

Variations on the theme of the Kinetic Theory

We can carry this molecular oscillation theory one step further.

Suppose temperature-dependent molecular oscillation is mediated by oscillation of the individual atoms comprising the molecules. Suppose also that the oscillation of atoms around the centres of their masses is at a constant frequency, which is mass dependent and thus

9 Patterns in Fluid Flow Paradoxes – Variations on a Theme. UWO Graphic Services,1980; Postscript: p. 74.

10 Hamilton G: Coherent Sound Energy in Transition to Turbulence. UWO Graphic Services, 2008, pp. 63-66

11 ibid: p. 6

specific for each atom on the periodic table, with the frequency stability being akin to the frequency of a pendulum's oscillation – remaining stable regardless of the amplitude.

Thus, in a compound molecule, the amplitude of oscillation (that is directly proportional to the Kelvin temperature) of a molecule would be the net oscillation of the component atoms' oscillations, with the atoms linked by their interconnected electron "rings."

With increasing temperature of a solid, the adhesion bonds between molecules, characteristic of the solid state, are disrupted at melting point, while retaining the cohesion bonds that characterize the liquid state. With further heating, the cohesion bonds break at boiling point. The oscillation of the molecules now drive them apart by caroming off each other, creating a intermolecular mechanical repulsive force.

At a particular stage in the heating of a solid compound, such as a metallic ore, the amplitudes of the oscillations of the component atoms become enough to shake them loose from their molecular binding forces – breaking up the compound into its component atoms (e.g., the iron from the oxygen of ferrous oxide, in the heat of a blast furnace).

Periodic oscillations of electric fields create electromagnetic oscillations. The oscillation of atoms, which includes the electric fields of ***element-specific atomic electron rings***, should create electromagnetic emanations specific for their frequency of oscillation. The frequency of oscillation of an element would thus be dependent on its specific atomic weight, similar to the frequency of a pendulum being dependent on the length of the pendulum's arc. Thus, on heating, there would be a specific spectral pattern that would be characteristic of the ***frequency of oscillation of the atoms of each element and the makeup of its electron rings***. This is known to be true – with the heating of a compound producing a spectrograph specific for the component elements. This is spectrographic support for the atomic oscillation component of this modification of the Kinetic Theory.

The Inter-molecular Repulsive Force of the Gaseous State of Matter

When the intermolecular bonds of a liquid are severed at boiling point, the released gas molecules react as if there is an inter-molecular repulsive force, causing the gas to fill a closed container – with equal distribution of gas molecules.

Consider a pure virtual gas that will remain in the gas state as the temperature drops to absolute zero on the Kelvin scale. Consider that all the movements of molecules in an undisturbed gas are from oscillations about their centres of gravity with amplitudes directly proportional to the absolute temperature. There will be no oscillation at zero degrees K – the molecules are oscillation-free.

If the virtual gas is in a distensible container that exerts a constant pressure of one atmosphere, a specific mass of this gas will expand and contract directly in proportion to the absolute temperature. At zero degrees K, there will be no molecular vibration, with the motionless molecules being in contact with each other – and with the walls of the distensible container Now raise the temperature one degree. All molecules will now oscillate about their axes with amplitudes corresponding to one degree K. This will cause the molecules to collide with each other, with the molecular centres of oscillation becoming separated from one another by a minimum of one diameter of the oscillation amplitude and separated from the walls by ½ a diameter.

Under the specified conditions, as the temperature rises, the amplitude of oscillation will rise, directly proportional to the Kelvin temperature scale. (In a closed container of fixed dimensions, the pressure exerted by limiting the amplitude of molecular oscillation will increase directly with the rise in temperature).

Releasing the gas to the open, the collisions between the vibrating molecules cause them to be caromed away from each other – imitating the effect of an inter-molecular repulsive force. Thus, it is proposed that the observed intermolecular repulsive force is mechanical – based on temperature-induced oscillation of the gas molecules and elastic rebounding from inter molecular collisions.

One can understand that, restricting the increase in the amplitude of vibration of the gas molecules by an increase in temperature, when in a confined space, will increase the viscosity by increasing vibratory energy ("roughness" of laminae) and will increase the pressure between adjacent laminae, like an automobile clutch. This explains why the viscosity of gases varies directly with the temperature. In liquids, as the temperature rises, the cohesive bonds which are characteristic of the liquid state of matter, are stretched and weakened,[12] causing the viscosity to drop, with the viscosity varying inversely with the temperature.

[12] Hamilton G: Coherent Sound Energy in Transition to Turbulence. UWO Graphic Services, 2008, pp. 63-68

Tyndall: "Sonorous Vibrations" (Coherent Sound) Mediate Transition (1867)

In 1867, Sir John Tyndall proposed a theory of the cause of transition to turbulence that bears a striking similarity to the coherent-sound-induced transition to turbulence theory under discussion. Tyndall's analysis, using very primitive apparatus, postulated that fluid friction along the sides of the tube created vibrations (i.e., sound waves) in the fluid.[13]

In this same paper, Tyndall experimented with the effect of coherent sounds on a flat flame that was just below a turbulent flow rate. In this phenomenal "sound sensitive" flow rate zone, specific musical notes ("sonorous vibrations") caused the immediate onset of turbulence – the flow rate dropped (the flame "ducked") and, simultaneously, a loud roaring sound ("flaring") emerged. Tyndall proposed that the particular external sounds, which triggered turbulence in his jets, had wavelengths that synchronized most nearly with the waves produced by the gas, thus amplifying them.

Tyndall concluded that: *"the sonorous vibrations (coherent sound), by acting on the gas in the passage of the burner, become equivalent to an augmentation of pressure………. In fact we have here revealed to us the physical cause of flaring……… In the orifice of the burner, the gas encounters friction, which, when the force of transfer is sufficiently great, throws the issuing stream into the state of vibration that produces flaring. …………… All sounds are not equally effective on the flame; waves of special period are required to produce the maximum effect. The effectual periods are those which synchronize most nearly with the waves produced by the friction of the gas itself against the walls of the orifice."*

The specific musical notes (coherent sound), when perpendicular to a flat, fish tail flame that was close to transition to turbulence, induced turbulence and, simultaneously, caused 90 degrees of rotation of the jet, with the rotation persisting for the duration of the sound. This rotational effect in Tyndall's experiment was used a century later (1974) to explain the induction of rotation in an efflux water jet as turbulence onset.[14] [15]

Tyndall's diagram of a turbulent exit water jet displays axial rotation of the jet, similar to the rotation displayed in a turbulent jet from an arteriogram needle.[16] Furthermore, his diagrams show that specific musical sounds caused a similar spinning turbulent water jet to split into

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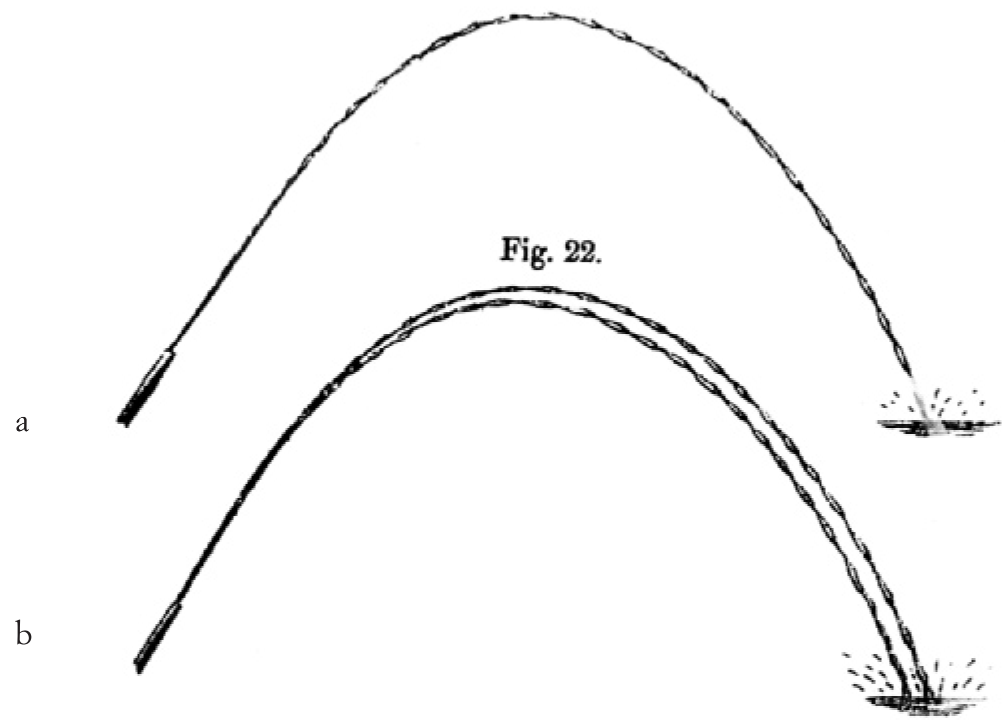
13 Tyndall J: On the action of sonorous vibrations on gaseous and liquid jets. Philosophical Magazine (1867); 33

14 Hamilton G: Patterns in fluid flow. Submission as work of original research in a gold medal competition for young researchers - Royal College of Physicians and Surgeons of Canada (September 1, 1974).

15 Hamilton G: Patterns in Fluid Flow Paradoxes – Variations on a Theme. University of Western Ontario Graphic Services (1980): Chapter 5, Sound sensitive jets and flames: pp. 29-33.

16 Ibid; Chapter 9: An amplification crescendo at transition: pp. 58-66.

two, three, or more, equal spinning columns which I deemed to be related to the 2, 3, or more, similar divisions described in the transverse flow patterns displayed by SPIV (stereoscopic particle image velocimetry) by Hof et al[17] in 2004 at the Delft University of Technology (TU Delft).

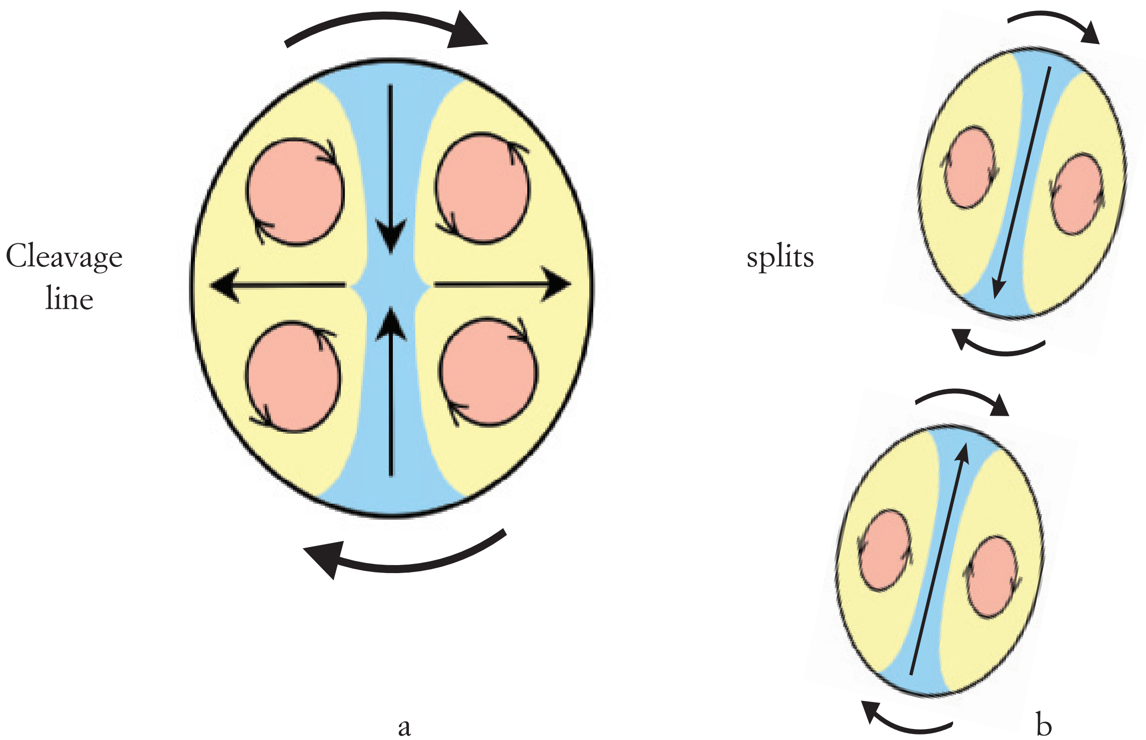


(a) Tyndall's 1867 spinning turbulent efflux water jet from a cylinder
(b) A specific note caused a split into two spinning columns

If Tyndall were to see the Hof-Delft, two three, or more, similar transverse divisions in turbulent flow in cylinders, using modern SPIV (stereoscopic particle image velocimetry), he would have linked them to the splitting of a cylinder's turbulent efflux jet into two, or more, similar spinning columns in response to a musical note. It is proposed that specific notes, added to the jet's transverse sound energy, amplify its coherent boundary layer sound. The split would occur at the sites where the centripetal streaming flows, generated in the boundary layer from opposite sides of the cylinder, collide before circulating back to the sound's origin in the boundary layer. Surface tension would immediately re-establish the ovoid shape of the two split spinning fluid columns; the higher-pressure areas (blue in the diagrams on next page) cause the widening of all the efflux jets.

[17] Hof B, van Doorne, CWH, Westerweel J, and Nieuwstadt FTM: First experimental observation of nonlinear travelling waves in turbulent pipe flow.

Laboratory for Aero and Hydrodynamics, Delft Iniversity of Technology.



(a) Two similar Hof-Delft transverse flow patterns in turbulence in a cylinder
(b) A specific note splits the efflux jet into two similar spinning columns

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Gavin Hamilton, MD

Gavin continues his life long research in fundamental Fluid Dynamics. His passion and desire to expand and share his theory has resulted in this and many other publications he has authored.

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